

# A SEARCH FOR DIRECT MUON PRODUCTION IN THE FORWARD DIRECTION

D. Buchholz  
California Institute of Technology

D. Eartly and Rolland P. Johnson  
Fermi National Accelerator Laboratory

R. L. Sumner  
Princeton University

O. Fackler  
Rockefeller University

H. Frisch and M. Shochet  
The University of Chicago

## ABSTRACT

We propose to search for direct muon production in the forward direction from 300 GeV protons incident on a heavy nuclear target. By using the first stage of the M1 beam as a source of a diffracted proton beam and the second and third stages of M1 as a spectrometer, one can make a measurement of the direct muon to pion ratio at values of  $x$  between 0.3 and 0.75. If this ratio is on the order of  $10^{-4}$ , the event rates are on the order of 800 direct muons/hr. at an  $x$  of .5. The modifications to the M1 beam are minor.

## I. Physics Motivation

Three of the most interesting recent results in high energy physics have involved lepton-hadron processes: 1) the scaling<sup>1,2</sup> of the structure functions in deep inelastic lepton-hadron scattering, 2) the production of hadrons in  $e^+e^-$  collisions at CEA<sup>3</sup> and SPEAR<sup>4</sup>, and 3) the observation of direct muon pairs at BNL<sup>5</sup> and directly produced single muons and electrons at NAL<sup>6,7,8</sup>, the ISR<sup>9</sup>, and Serphukov<sup>10</sup>. It is likely that, at very high energies, it will be in such experiments as these, rather than in standard strong interaction experiments, that one will learn about the fundamental structure of hadrons.

The SPEAR results, the BNL dilepton production, and the newly observed single lepton production all are surprising in that the coupling between hadrons and leptons is much stronger than conventional wisdom<sup>11</sup> would predict. There is also another experiment, the small angle muon pair electroproduction experiment at Cornell<sup>12</sup>, which sees an order of magnitude more muon pairs than one would expect. Moreover, Adair has reported<sup>13</sup> that at  $\sqrt{s} = 7.6$  GeV, the direct muon to pion ratio was on the order of  $10^{-4}$  in the forward direction, a value much greater than expected from electromagnetic decays of strongly produced particles. All of these enhancements are especially interesting in the light of the current excitement about theories which unify the strong, weak, and electromagnetic interactions, including some which involve a direct relationship between leptons and hadrons.<sup>14</sup>

The large dilepton production cross-sections found at BNL are related to the surprising SPEAR results on the constant cross-section for the production of hadrons.<sup>15</sup> It is not yet clear, however, whether or not the copious production of single leptons is related to either of these processes, or whether it has a more conventional, strong interaction source, such as the dileptonic decays of known vector mesons.

The present high energy data on single lepton production at large values of  $P_{\perp}$  show that the ratio of cross-sections for the production of direct muons and of pions ( $\mu D/\pi$ ) is a constant approximately equal to  $10^{-4}$  over a wide range in  $P_{\perp}$  and  $\sqrt{s}$ . Specifically, at  $\sqrt{s} = 23.7$  GeV the cross-section is constant from  $P_{\perp} = 1.5$  GeV to a  $P_{\perp}$  of 5.35 GeV.<sup>6</sup> A measurement<sup>16</sup> at  $\sqrt{s} = 19.4$  also finds the ratio  $\mu D/\pi$  is  $10^{-4}$ . Measurements at the ISR<sup>9</sup> (on electron production) at a  $\sqrt{s}$  of 53 GeV, at Serphukov<sup>10</sup> at a  $\sqrt{s}$  of 12 GeV, and at Fermilab<sup>8</sup> for  $11 \text{ GeV} < \sqrt{s} < 24 \text{ GeV}$  also find approximately the same ratio for  $\mu D/\pi$ . One can thus conclude that in the kinematic region around  $90^\circ$  in the c.m. and at fairly large values of  $P_{\perp}$  there is no systematic energy or  $P_{\perp}$  dependence in the ratio  $\mu D/\pi$ .

It is possible that these leptons come from the dileptonic decays of vector mesons, such as the  $\rho$ ,  $\omega$ , and  $\phi$ . If we assume that each of these is produced with equal cross-section, the production of each of the vector mesons would have to be 1.8, 3.0 and 4.6 times the pion production for  $P_{\perp} = 1.5, 3.0$ , and 4.5 GeV, respectively. While these numbers seem large, and a mechanism that makes the vector meson production grow in such a way that  $\mu D/\pi$  stays constant would seem unusual, vector mesons cannot be ruled out as a source for the high  $P_{\perp}$  leptons.

If the ratio  $\mu D/\pi$  were also equal to  $10^{-4}$  at low  $P_{\perp}$  for a wide range of  $x$ , the vector mesons would have to be produced at least as copiously as pions in strong interactions. Leipuner et al. have reported<sup>13</sup> that in a Brookhaven experiment<sup>17, 18</sup> at  $\sqrt{s} = 7.6$  GeV the direct muon to pion ratio was on the order of  $10^{-4}$ . These data rule out the known vector mesons as the source of the single leptons: the  $\rho$  meson production has been measured at  $\sqrt{s} = 7.0$  GeV by Blobel et al.,<sup>19</sup> who find that the  $\rho$  production cross-section is approximately 1/15 of the pion cross-section.

The measurements proposed here would extend the measurements of Adair to higher energies and a wider range in  $x$ . The constancy of the ratio  $\mu_D/\pi$  at high  $P_\perp$  over a wide range in  $P_\perp$  and  $\sqrt{s}$ , where the cross section changes by more than a factor of  $10^5$ , raises the possibility that, barring phase space effects, the ratio is a constant independent of  $x$  and  $P_\perp$ . It is possible that the change in  $\mu_D/\pi$  with  $x$ , as seen by Leipuner et al. at Brookhaven National Laboratory, is in fact a threshold effect, i.e., a heavy particle is the source of these muons. This seems to be corroborated by the measurements at the ZGS by Lamb et al.<sup>20</sup>, who have showed that direct muons are not seen at  $P_\perp = 1.4$  GeV at a level of approximately  $3-4 \times 10^{-5}$ . The fact that the c.m. energy available at NAL is probably many times the masses of the source of these muons allows this measurement over a wide range of  $x$  without the complicating effects of being near the edge of phase space.

We should note that the proposed search would be sensitive to muons from other exotic sources, such as charmed particles or heavy leptons. For example, if charmed particles are as copiously produced as kaons and decay weakly into leptons with a branching ratio of 10%, one would expect a strong muon signal at a level of approximately  $10^{-3}$  to  $10^{-4}$  of the pion flux. This is certainly a possible candidate for the source of the muons.

### Experimental Technique

The diffracted proton beam impinges on a heavy variable density target approximately 6 absorption lengths thick. Immediately downstream of this a fixed 10' steel absorber filters out the hadronic cascade. The target consists of plates with variable spacing between them such that the average density is variable by a factor of four. (See Fig. 1). The muon flux will be measured at three different densities, and the production extrapolated to infinite density, i. e., zero effective decay length. Figure 2 shows such an extrapolation. The intercept of the line at zero effective decay length gives the component of muons which are direct - that is, do not come from the decay of long-lived particles such as the  $\pi$  and the K.

The slope of the extrapolation versus density measures the pion flux, thus measuring the direct muon to pion ratio. To do this, one need only know the shape of the pion production spectrum, and not the absolute normalization. If one parameterizes the pion spectrum in the forward direction versus  $x$  by the experimentally determined function<sup>21</sup>

$$\frac{d\sigma}{dx} \propto x(1-x)^4$$

one can calculate for a given slope the pion production. Conversely, for illustrative purposes, Fig. 2 shows the extrapolation plot as calculated for  $x = .5$  assuming a value of  $\mu_D/\pi$  of  $10^{-4}$ , and a pion spectrum  $\frac{d\sigma}{dx} \propto x(1-x)^4$ .

The error bars shown represent a shift of data taking per point assuming the event rates are 1/3 of those calculated.

The value of  $x$  for a measurement is determined by the ratio of the momenta set in the downstream stages of the beam relative to that of the first stage. Thus changing the  $x$  value measured is very easy.

### Experimental Apparatus

The beam layout is shown in Fig. 3. We propose to use the first stage of the M1 beam line to transport a 300 GeV/c diffracted proton beam to the target located just upstream of  $B_{7-9}$ . The incident beam intensity will be monitored upstream of the target. The beam line downstream of the variable density target is used as a spectrometer to select, momentum analyze, and transport any resulting muons to a muon detector similar to that presently in use in the M1 beam line.

The quadrupoles  $Q_{7-9}$  focus the beam horizontally at the 900 ft. level where a scintillation counter  $S_2$  defines a  $\pm 7\%$  momentum bite. The spectrometer's acceptance is  $0.36 \mu\text{ster}$  at a mean production angle of  $1.6 \text{ mr.}$  The quadrupoles  $Q_{10-13}$  focus the beam upstream of the muon detector. The other scintillation counters are used to define the beam.

The muon detector would be located in one of two possible positions: either at the upstream end of the meson detector building, or at the 1000 ft. region of the M1 beam line. (The latter location for the muon detector would result in a factor of 5 increase in the yields discussed on p. 6 of this proposal.)

The only equipment needed that is not already in use in the M1 beam line is the variable density target, the scintillators  $S_1-S_6$ , miscellaneous other scintillators for antis, and the modification of the 200' vacuum pipe into a Čerenkov counter. Also, if necessary, a simple new muon detector of steel and scintillator would be constructed.

We should note that the M1 beam line may not be unique in being suitable for this experiment. We are looking into other beam lines which have the capability of being run as two separate focusing dispersive stages, with a vacuum pipe upstream of the suitable target location.

### Event Rates

We assume a diffracted proton beam of  $5 \times 10^8$  protons/pulse incident on our target, and make the assumption<sup>22</sup> that the production increases by a factor of 6.8 at 225 GeV/c in going from the measurements at 3.6 mr to a 1.6 mr production angle. The spectrometer acceptance,  $\Delta\Omega \frac{\Delta p}{p}$ , is  $5.8 \times 10^{-8}$  steradians. We can thus calculate the event rates shown in Table 1. The rates are shown for  $\pi^-$ ; the  $\pi^+$  rate is about a factor of 3 higher. The event rates in direct muons/hr are shown in Fig. 4.

TABLE 1

Spectrometer Momentum	X	$\pi^-$ /pulse	$\mu_D^-$ /pulse *
90	0.3	$2.7 \times 10^4$	2.7
150	0.5	$1.3 \times 10^4$	1.3
175	0.58	8000	0.8
200	0.67	4000	0.4
225	0.75	2000	0.2

\*assuming  $\mu_D/\pi = 10^{-4}$

If the muon detector were to be located in the 1000' region rather than in the meson detector building, the rates would be a factor of five higher than shown in Table 1 or Fig. 4.

We should emphasize that a search for a rare process like direct lepton production is not by nature a high statistics experiment.

The smallest event rate listed in Table I, while appearing very small, is a factor of 100 larger than the smallest direct lepton rate successfully measured in the high  $P_{\perp}$  experiments.<sup>16</sup>



### The A Dependence of Direct Muon Production

If the direct production rates are sufficiently large, we propose to study the  $\mu_D/\pi$  ratio as a function of the atomic number (A) of the target. The production depends on the atomic number of the target nucleus in a fashion determined by the nature of the production process itself. Measurements at high  $P_\perp$  have shown<sup>6</sup> that the muon production has the same A dependence as the pion production. However, the pion production at high transverse momentum is not yet understood. The A dependence of the pion production itself is not the  $A^{2/3}$  one might expect, but rises with  $P_\perp$  to an  $A^{1.1}$  dependence<sup>23</sup>.

## Backgrounds

We consider as background any muons that are detected in the counter telescopes and in the muon detector and which are not directly produced. There are three sources of background of which we have thought:

- 1) Muons from the decay in flight of  $\pi$ 's and K's produced in the cascade inside the target and absorber.
- 2) Muons from hadrons which emerge from the downstream end of the absorber
- 3) Muon contamination in the beam.

The component of muons from process 1 can be measured by changing the effective density of the target and, as described above, is essential in the measurement of  $\mu_D/\pi$ .

The background from process 2 should be very small, but if any exists, it is directly measurable. It is hard to estimate how many fast pions will emerge from a block 18 absorption lengths long on which protons have impinged, but it should be very small. However, of those pions which do emerge, less than 3% decay. Thus by measuring the  $\pi$  flux downstream of the absorber at a given  $x$  one can measure the muon contribution from pion punchthrough. This can be done by using the threshold counter downstream to separate protons from pions, and the muon detector to identify hadrons as distinct from muons.

The third source of background, muon contamination of the incoming beam, is the most dangerous. Muons in the beam would behave just like directly produced muons in that they are independent of the decay distance. One can make only a crude estimate of this background - to

really know how serious it is, one has to try.

We would take the following steps to suppress this background:

1) One would expect the muon background to be spatially broader than the diffracted proton beam. One can measure this with counters downstream of the absorber. 2) One can define the incoming proton beam with anti counters on the upstream side of the berm at the 450' region and veto events in which protons interact in the transport system close to the absorber. 3) We would add a mirror, phototube, and gas system to the 200' vacuum pipe upstream of the absorber to turn it into a threshold counter capable of separating protons from muons. This should allow a rejection factor against muons of at least 100, and would allow the measurement of the muon contamination.

A crude estimate of the background, probably good to an order magnitude, assumes that these muons came from proton interactions in the beam transport upstream of the target. If one assumes that 10% of the beam is lost, and that on the average a pion produced travels 50 ft. before it interacts with something, and with the rejection of the Cerenkov counter, the background will occur at a level of  $< 10^{-6}$ . However, there is a large solid angle factor suppressing this number, depending on where the pions are made.

Comparison of this Proposal with NAL Experiment 48

The pending FNAL experiment 48 of Adair and co-workers to measure the intensity and polarization of directly produced muons does not have much overlap with this proposal. We are proposing a quick systematic search in the forward direction at a series of well determined values of  $x$ , at a fixed small  $P_{\perp}$ . This would be an immediate follow-up to the high  $P_{\perp}$  single lepton discoveries. In contrast E48 is larger, more sensitive, but will measure the intensity at large  $P_{\perp}$  averaged over a range of values in  $P_{\perp}$  and  $x$ .

The major differences between of the two experiments are listed below:

1. Sensitivity. Our present proposal is far less sensitive than E48 should be in terms of the cross section one could measure if there were no background. The apparatus we propose has a solid angle of  $3.6 \times 10^{-7}$  steradians. The 6' x 6' counters in the E48 proposal subtend a solid angle at 700' of approximately  $8 \times 10^{-5}$  steradians. Because we are using a secondary beam, we are limited to approximately  $5 \times 10^8$  protons/pulse, while E48 can use the extracted proton beam, i.e., on the order of  $5 \times 10^{12}$ /pulse. Thus while E48 is capable of reaching cross sections in the  $10^{-38}$  range, our proposal would reach only to the  $10^{-32}$  range.

However we should point out that if  $\mu_D/\pi = 10^{-4}$  at  $x = .5$ , the cross section we wish to measure is on the order of  $10^{-30}$ . At the estimated rate of 800 direct muons per hour we would then have a good measurement of  $\mu_D/\pi$  in a shift of running at one  $x$  value. It does not require extraordinary sensitivity to measure the direct muon production if in fact the  $\mu_D/\pi$  ratio is on

the order of  $10^{-4}$ . This is the reason that E48 emphasizes the region where  $P_{\perp}$  is large, because it is there that the background due to pion decay is small. In fact, if  $\mu_D/\pi = 10^{-4}$  at  $x = .5$ , the direct muon signal would be approximately 10 times the background due to pion decay. It is the possibility of such a large signal that motivates a quick search.

2. Kinematic Region of Search. We propose to measure the ratio of the direct muon flux to the pion flux at very small values of  $P_{\perp}$ , i. e.,  $P_{\perp} < 300$  MeV. We would perform this measurement at discrete values of  $x$  between  $x = .3$  and  $x = .75$  with a precision in  $x$  of  $\pm 5\%$ . These measurements would determine whether the results at high  $P_{\perp}$  hold true in the region where the more conventional strong interactions are known to dominate, i. e., at low  $P_{\perp}$ . We emphasize that both the  $x$  and the  $P_{\perp}$  of the muon would be measured accurately in the magnetic spectrometer downstream of the target.

In contrast, the E48 proposal does not determine either the momentum or the  $P_{\perp}$  of the muon very well. For instance at an  $x$  of  $.5$ , the uncertainty in  $P_{\perp}$  will be on the order of 2 GeV, and the uncertainty in  $x$  will be on the order of 50%. This lack of resolution will result in averaging the  $\mu_D/\pi$  ratio over the kinematic variables.

The E48 apparatus is not sensitive in the forward direction. Because they emphasize the detection of muons with  $P_{\perp}$  greater than 2 GeV, their apparatus is situated to the side of the undeflected beam line. In contrast, the present proposal accepts muons only in the forward direction, and with  $P_{\perp}$ 's of less than 300 MeV.

Changes necessary to the M1 beam line

The changes needed to use the M1 beam line result from using the first stage to transport a diffracted proton beam and the second stage as a muon spectrometer.  $Q_{1-2}$  require an excitation current of 110 amps rather than the nominal good field limit of 100 amps. To be really conservative the two Acme power supplies powering these quads can be ramped.

It would be necessary to power  $B_{5-6}$  and  $B_{7-9}$  separately - they are now run in series. This can be done by severing one bus from the 5 power supplies now in the M2 service building and changing a second supply over to the current regulator mode. The  $B_{5-6}$  magnets would require 5,300 amps which the Transrex supplies presently powering the magnets would supply. To provide this current the calibration of the transducer must be changed, which we are told is a fairly minor job. These magnets will have been ramped by the time this experiment would begin, so that the power dissipation would be under control.

Some shielding would need to be added outside of the service door to the M1 tunnel downstream of the variable density target. Installing the variable density target would require removing some vacuum pipe and the C 7 collimator upstream of  $B_{7-9}$  in order to increase the length of the air gap in that region. We would like to attach a Čerenkov counter head to the vacuum pipe in the beam upstream of the variable density target.

The installation of the variable length target, the scintillation counter and the above changes could be accomplished over several of the Thursday shutdowns and should not necessitate any interruption in the utilization of the M1 beam line.

### Running Time

We request a short test run in the M1 beam line. We would need an integrated proton intensity of about  $10^{17}$  protons over one week's time in order to tune the beam and the electronics, check backgrounds, and make a measurement of the direct muon production at one  $x$  value. Most of the electronics setup and testing can be done in a non-interfering parasitic mode.

If direct muons are produced at  $10^{-4}$  of the pion flux, we can make a detailed measurement at one value of  $x$  in a day's running. For instance, at  $x = .5$ , the projected rate is for 800 direct muons per hour, leading to approximately 16,000 direct muons/day.

Given the presence of direct muon production at a reasonable level, we would like at a later time an integrated proton flux of  $2 \times 10^{17}$  to measure the  $\mu^+$  and  $\mu^-$  production spectrum with  $P_{\perp} \leq 400$  MeV/c over a wide range in  $x$ . Under normal running conditions, this flux could be obtained in a week.

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Figure Captions

Figure 1. The variable density target configuration.

Figure 2. A typical extrapolation plot as calculated for  $x=0.5$  and  $\mu_D/\pi = 10^{-4}$ .

Figure 3. The M1 beam line and apparatus layout.

Figure 4. The rate for detecting direct muons for  $3 \times 10^{12}$  300 GeV protons/pulse on the meson lab target.

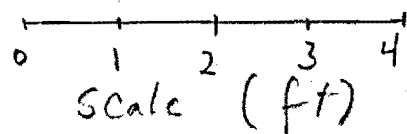
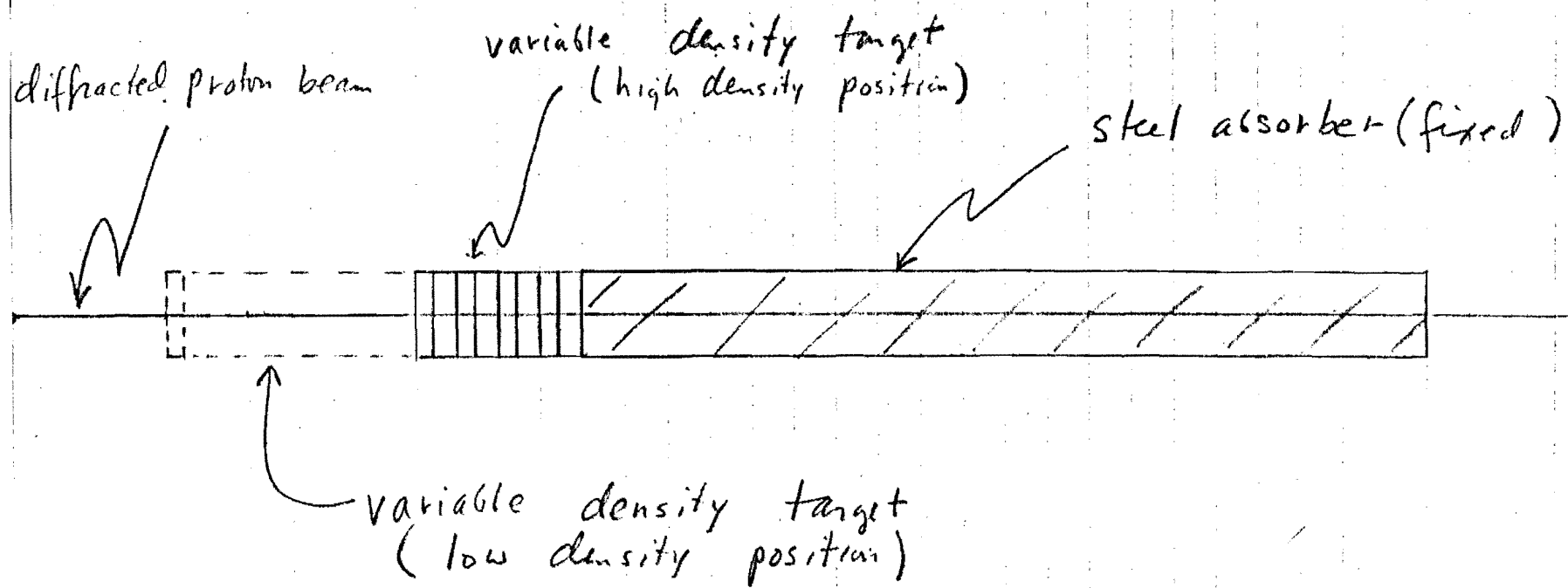


Figure 1

$\rho_U \equiv$  density of Uranium  
 $\rho \equiv$  average density of  
 absorber

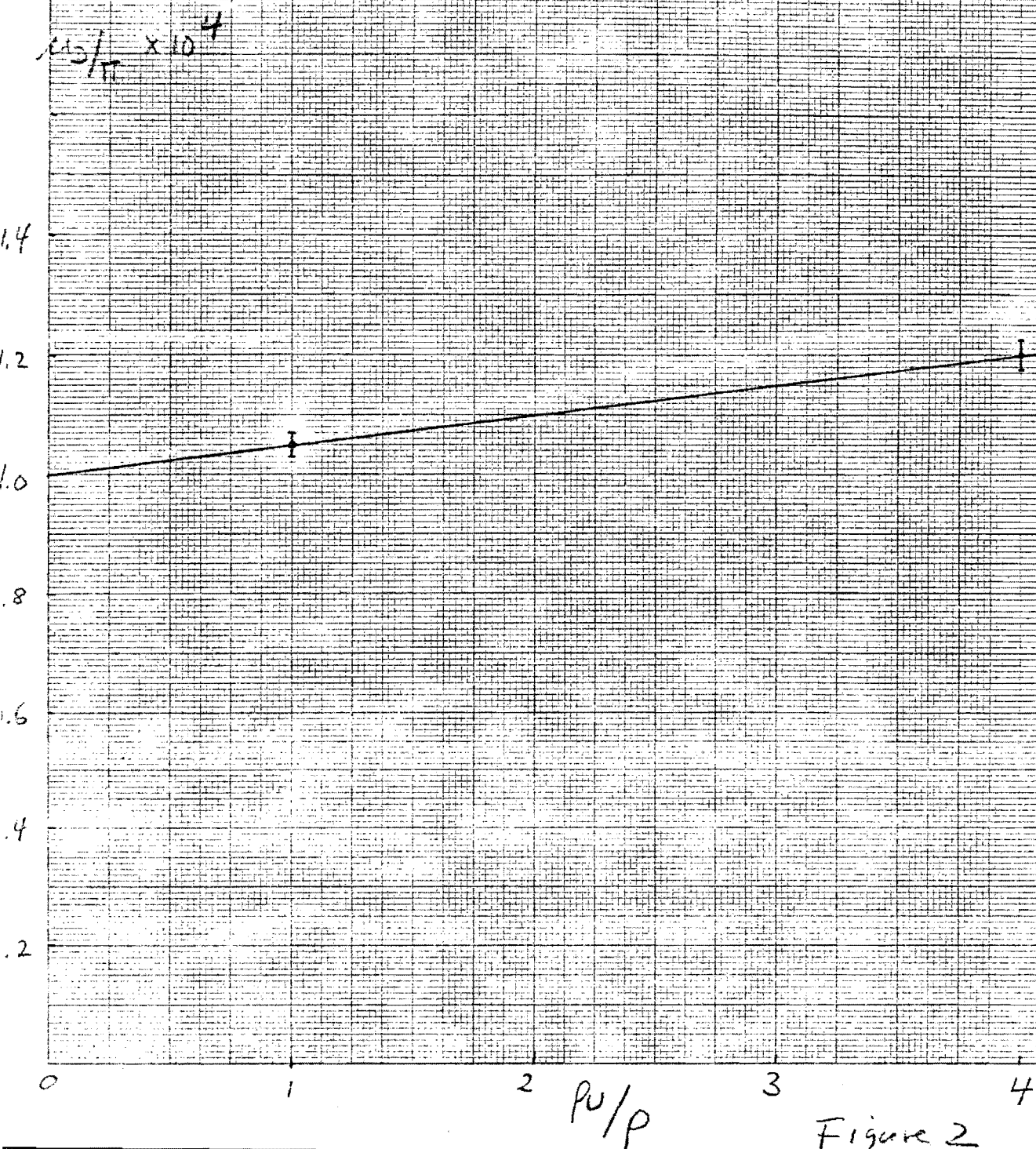


Figure 2

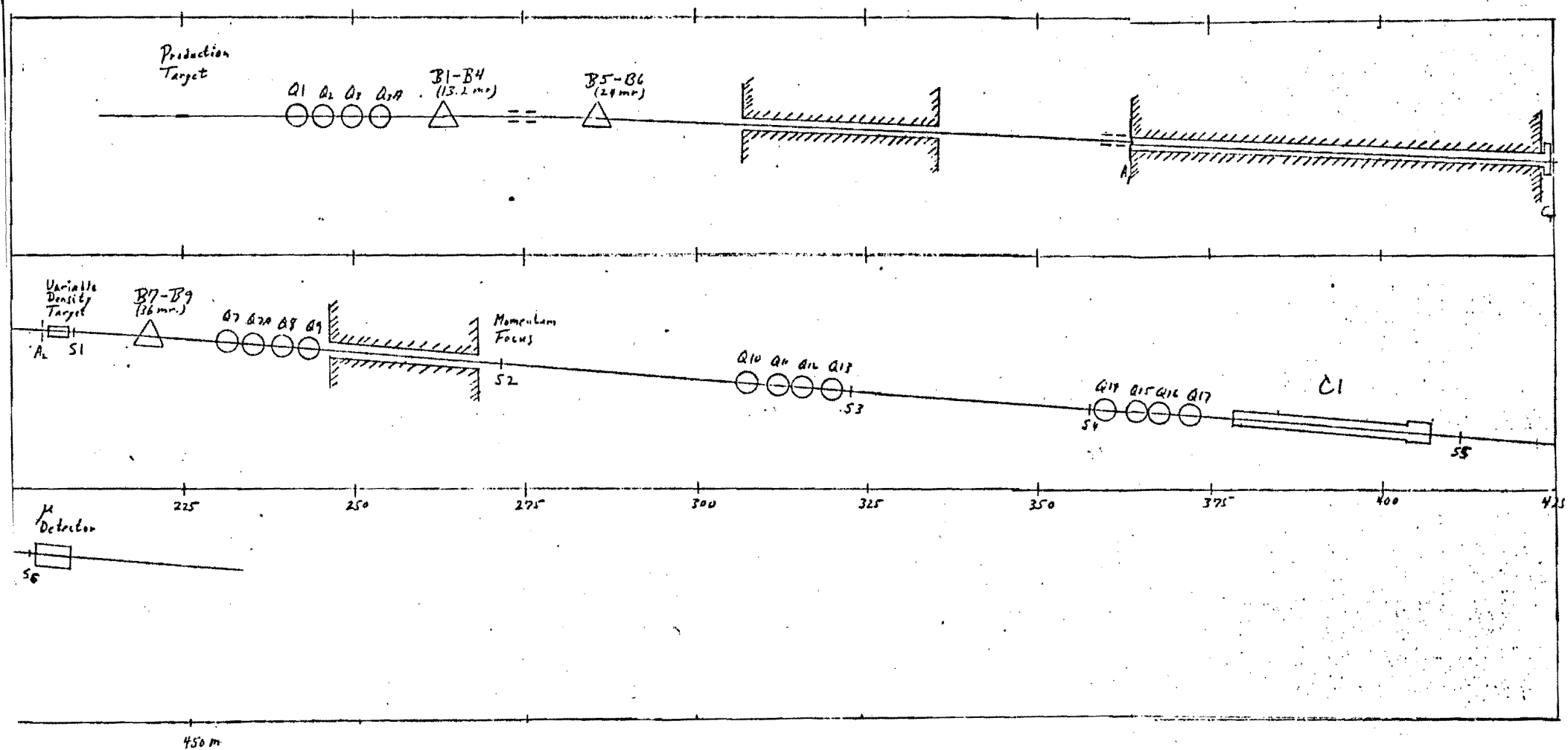


Fig 3

DIRECT  $\mu$ 's / HOUR

10000-

1000

100

10

46 5810  
SEMI-LOGARITHMIC  
3 CYCLES X 140 DIVISIONS  
KEUFFEL & ESSER CO.

P (GeV/c)

Figure 4

